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13. SUPPLEMENTARY NOTES The review, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Dept. of the Army position, policy, or decision, unless so designated by other					
14. ABSTRACT documentation.  We followed a coordinated two-pronged approach to advance our understanding of the structure, interannual and seasonal variability of the Japan Sea's Tsushima Current: observational data analysis and theory/ modeling. 1. Observational data analysis: Using high quality <i>in situ</i> hydrographic data and TOPEX POSEIDON altimetric data, define the mean, seasonal and interannual variability of Tsushima Current and sea level in the context of the geometry of the eastern boundary of the Japan Sea and distribution of warm core eddies. 2. Theory/Modeling: Through analytical models, we examine the dynamics of the Tsushima Current as it interacts with topography, coastal boundary and air-sea fluxes.					
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## **Studies of the Tsushima Current**

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Award Number: N00014-99-1-0092

JES Web site: [http://sam.ucsd.edu/onr\\_jes](http://sam.ucsd.edu/onr_jes)

We followed a coordinated two-pronged approach to advance our understanding of the structure, interannual and seasonal variability of the Japan Sea's Tsushima Current: observational data analysis and theory/modeling.

1. Observational data analysis: Using high quality *in situ* hydrographic data and TOPEX POSEIDON altimetric data, define the mean, seasonal and interannual variability of Tsushima Current and sea level in the context of the geometry of the eastern boundary of the Japan Sea and distribution of warm core eddies.
2. Theory/Modeling: Through analytical models, we examine the dynamics of the Tsushima Current as it interacts with topography, coastal boundary and air-sea fluxes.

Publications [published, submitted, in near completion]

1. Gordon, A. L., et al. (2002), Intra-Thermocline Eddies: Using data obtained by the JES program in spring/summer 1999 and winter 2000, by the *Hakuho-maru* and *Revelle* cruises, along with archived data including the suite of AXBT profiles, a family of sub-surface eddies within the warm regime of the Japan Sea are identified. The characteristics of these intra-thermocline eddies are described.
2. A. Gordon and C. Giulivi (2002) " Interannual Variability of Sea Surface Height in the Japan/East Sea" soon to be submitted to the JES special Deep-Sea Research volume: Satellite altimetric data from the period September 1992 to January 2002 reveal the presence of interannual variability of sea surface height (SSH) within the Japan/East Sea (JES).
3. Ou, H. W. (2001): A model of buoyant throughflow: With application to branching of the Tsushima Current. *J. Phys. Oceanogr.*, **31**, 115-126.
4. Ou, H. W. and A. Gordon (2002): Subduction along a mid-ocean front and the generation of intra-thermocline eddies: a theoretical study. *J. Phys. Oceanogr.*, **32**, 1975-1986.

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5. Ou, H. W. (2002): On the cooling of a buoyant boundary current. *Deep Sea Res.*, submitted to the JES special Deep-Sea Research volume

Summary of Results:

1. Intra-Thermocline Eddies: [collaborative research with: Craig Lee (UW), Amy Bower and Heather Hunt Furey (WHOI), Claudia F. Giulivi (LDEO) and Lynne Talley (SIO) ]: Anticyclonic eddies with strong surface expressions in SST and sea level are commonly associated with boundary current instabilities. In the Japan Sea such eddies are produced as the Tsushima Current maneuvers around the Noto and Oki Island promontories. Another class of ocean eddies are sub-surface, called intra-thermocline eddies. They may represent winter mixed layers that have been subducted into the adjacent stratified fluid. Intra-thermocline eddies were detected in the Japan Sea by CTD data obtained by the R.V. Revelle cruises in May-July 1999 and January-February 2000, and the R.V. Hakuho-Maru cruise in October 1999. Temperature and salinity sections collected during the Hakuho-Maru cruise show a relatively homogeneous layer of 9 to 10°C water of 34.12 salinity extending from 100 to 240 m. It is observed at three sequential stations covering a distance of 42 km, centered at 37°54'N and 133°36'E. A thinner thermostad is observed at adjacent stations, suggesting a lens diameter of at least 85 km. The T/S structure within the lens displays a small negative salinity anomaly in comparison to adjacent T/S stratification. In Temperature/Oxygen space the lens displays positive oxygen anomalies, a sign of winter mixed layer ventilation. The Revelle station array obtained May-July 1999 detected near 38°10'N, 134°00'E what is probably the Hakuho-Maru 10°C lens, suggesting a slow drift (0.5 cm/s) to the southwest. The Revelle January 2000 cruise crossed over the edge of what is likely the same lens at 37°45'N, 134°E, suggesting slow drift to the southeast. The summer Revelle cruise finds similar 10°C intra-thermocline eddies at 2 other sites: 37°50'N, 131°00'E and 38°45'N, 137°35'E. The negative salinity anomaly is greater in the eastern sites than in the western sites. Sea level over the lenses is slightly higher than the surrounding regions, but as the baroclinic shear below the lens is nearly equal to but opposite in sign of the shear above, the sea level expression of the intra-thermocline eddies is weak. In this regard they are distinct from the warmer eddies generated at the Noto and Oki Island promontories. It is suggested that the 10°C intra-thermocline lenses are formed within a quasi-stationary meander of the western branch of the flow through Tsushima Strait. There, in winter, off the coast of Korea a winter mixed layer is observed with characteristics of the 10°C intra-thermocline eddy. The winter mixed layer is then subducted into the mid-thermocline of the Tsushima Current. It is possible that the lenses are carried eastward close to the sub-polar front, where low salinity water is incorporated, and then moves south towards the Japan.

2. Interannual Variability of Sea Surface Height in the Japan/East Sea: Satellite altimetric data from the period September 1992 to January 2002 reveal the presence of interannual variability of sea surface height (SSH) within the Japan/East Sea (JES). Over the deep Yamato Basin, just south of the Japan/East Sea subpolar front, there is evidence of a biennial oscillation, which has been reported earlier. Over a more extensive area, SSH interannual variability amounting to approximately 15 cm appears to be nearly in phase with the Pacific Decadal Oscillation (PDO). During the positive (negative) phase of the PDO the Aleutian Low becomes deeper (weaker) and shifts to the south

(north), the westerlies over the North Pacific strengthen (weaken). Positive PDO has been dominant since 1976, though periods of near zero PDO have occurred, such as in the early 1990s. In late 1998 the PDO appears to have switched to a negative phase, remaining negative to the end of the altimeter record used in this study. When PDO is positive the JES SSH is relatively low; during the PDO negative phase, the JES SSH is relatively high. The highest SSH is evident from late 1998 to the end of the record in January 2002. In 1994 when the PDO is near zero, SSH was also higher than in prior or later years when the PDO was positive. The link between the JES SSH to PDO is due to a combination of steric variability (upper layer temperature and salinity variability) and of the barotropic effects presumably induced by changes in inflow/outflow. The latter may be associated with changes in the Kuroshio transport which does display PDO dependence.

3. In Ou (2001), we examine the dynamics of a buoyant flow through a strait through a simple reduced-gravity model. Assuming the flow to be hydraulically controlled so that the transport is maximized, we determine the flow structure in the upstream basin, during its transit through the strait and along the downstream coast. It is found in particular that the combined effect of friction exerted by the sill and stretching of the buoyant layer as it exits the strait may cause the downstream flow to exhibit two velocity maxima --- along the layer outcrop and the coastal boundary. When applied to the Tsushima Current, the required conditions for branching are amply satisfied, the model thus provides a plausible explanation of this prominently observed feature. In addition, a favorable comparison between predicted and observed transports supports the hydraulic control of the flow.

4. In Ou and Gordon (2002), we examine the subduction process in the frontal zone. Through simple vorticity balance, we show why subduction of the mixed layer water into the thermocline is an inherent frontal process, and why it necessarily leads to the generation of intra-thermocline eddies. The model shows additionally that the subduction rate is mainly a function of the mixed-layer depth and relatively insensitive to the horizontal mixing processes. The model eddies are preferably anti-cyclonic and exhibit a wide range of size --- both predictions are consistent with observations. Through entrainment cooling, these eddies, with their characteristic domes, may leave imprints in the surface temperature, giving rise to the observed meandering of the front, even in the absence of instability.

5. In Ou (2002), we examine the evolution of a buoyant boundary current, such as the Tsushima Current, as it is subjected to surface cooling. It is found that the diminished buoyancy does not alter either the overall strength of the current or the cross-stream difference of the square velocity, which leads to a downstream enhancement of the net shear regardless of its upstream sign. As a consequence, if the upstream flow contains comparable near-shore and offshore branches, this parity would persist; but if the former is weaker to begin with, it may be stagnated by cooling, with the ensuing generation of the anti-cyclonic eddies. Some of the model predictions are consistent with observations from the Tsushima Current.

## REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on back)

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The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (9000-0095), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

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1.a. NAME OF CONTRACTOR/SUBCONTRACTOR

Trustees of Columbia Univ.  
1210 Amsterdam Ave  
254 Engin. Ave - MC2205  
N.Y. 10027

c. CONTRACT NUMBER

NO0014-990092

d. AWARD DATE

(YYYYMMDD)

b. ADDRESS (Include ZIP Code)

Same

a. INTERIM

b. FINAL

c. CONTRACT NUMBER

Same

d. AWARD DATE

(YYYYMMDD)

a. FROM

11/1/00

b. TO

10/31/02

### SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR" (None, "so state")

NAME(S) OF INVENTOR(S) (Last, First, Middle Initials)	TITLE OF INVENTION(S)	DISCLOSURE NUMBER, PATENT APPLICATION SERIAL NUMBER OR PATENT NUMBER	ELECTION TO FILE PATENT APPLICATION (X)		CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER (X)	
			(1) UNITED STATES	(2) FOREIGN	(a) YES	(b) NO
a.	b.	c.	(a) YES	(b) NO	(a) YES	(b) NO

f. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR

(1) (a) NAME OF INVENTOR (Last, First, Middle Initials)

None

(2) (a) NAME OF INVENTOR (Last, First, Middle Initials)

(b) NAME OF EMPLOYER

(b) NAME OF EMPLOYER

(c) ADDRESS OF EMPLOYER (Include ZIP Code)

(c) ADDRESS OF EMPLOYER (Include ZIP Code)

### SECTION II - SUBCONTRACTS (Containing a "Patent Rights" clause)

NAME OF SUBCONTRACTOR(S)	ADDRESS (Include ZIP Code)	SUBCONTRACT NUMBER(S)	FAR "PATENT RIGHTS" d. (1) CLAUSE (2) NUMBER		DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S)	(2) DATE (YYYYMM)	SUBCONTRACT DATES (YYYYMMDD)
			(1) CLAUSE	(2) DATE (YYYYMM)			
None							

### SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR (or required if, (X as appropriate))

I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all

"Subject Inventions" have been reported.

a. NAME OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR  
OFFICIAL (Last, First, Middle Initials)

Gordon, Arnold, L.

Principal Investigator

c. SIGNATURE

*Arnold Gordon*

d. DATE SIGNED

11/7/02

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